Dinosaur footprints from the lower Jurassic of Mount Morgan, Queensland

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ABSTRACT

Over 190 partial and complete dinosaur prints which include six trackways are preserved in the ceilings of a disused clay mine near Mount Morgan central eastern Queensland, Australia. These represent the best record of Early Jurassic dinosaur footprints thus far discovered within Australia. *Anomoepus* dominates with other morphologies present including, *Grallator*, cf. *Eubrontes*, and *Skartopus* and several indeterminate prints. Only one possible manus print was observed. All preserved tracks are short walking tracks.

❒ *Lower Jurassic, dinosaur trackways, ornithopod, theropod, dinosaur footprints, Razorback Beds, Mount Morgan.*

Early Jurassic records of dinosaurs in Australia are scant with no Early Jurassic dinosaur skeletal material known, and only isolated occurrences of dinosaur prints known in Queensland (Bartholomai 1966; Bartholomai *in* Hill, Playford & Woods, 1966; Thulborn 1994). Dinosaur prints and trackways are known in Australia from the mid-Triassic onwards into the Late Cretaceous (Thulborn & Wade 1984; Thulborn 1998) and have proved essential in delimiting the diversity and evolutionary importance of otherwise unknown elements of the dinosaurian faunas of the continent. Dinosaur footprints have been recognised near Mount Morgan for over fifty years, but there has not been any documentation of their occurrence, composition and inferred palaeobiological information. Reconnaissance reports of this ichnofauna were made by Staines (1954), Bartholomai (1966) and Molnar (1991), but only isolated prints and no trackways were figured. This work concerns the dinosaur footprints prints exposed in the 'Fireclay Caverns' mine at Mount Morgan and the few trackways preserved in the ichnological assemblage.

Mount Morgan gold and copper deposit was exploited between 1882 and 1990. In support of mining operations, were a series of clay mines supplying raw material with which to make bricks for the smelting furnaces. These 'fireclay caverns' operated spasmodically between 1886 and 1925. Activity in the mine and subsequent chemical weathering exposed the lowermost surfaces of at least three layers of dinosaur footprints. A prime reason for the delay in investigating these occurrences of trackways was that they are exposed on the ceiling of the mine, 10-12 m above the mine floor. This rendered replication, photography or removal

difficult. One small area of footprints was exposed in a suspended drive and was within 4-5 metres of the mine floor. It was these prints that Staines (1954) photographed.

STRATIGRAPHIC AND SEDIMENTOLOGICAL SETTING

Mount Morgan is located 38 km SW of the regional centre of Rockhampton, central eastern Queensland (Fig. 1). A ~65 m thick succession non-marine Jurassic sediments unconformably overlies Devonian basement (Fig. 2) and has been commonly called the Razorback Beds (Playford & Cornelius 1967, Day et al., 1983). Studies by Playford & Cornelius (1967) of these units indicate a lowermost Jurassic age and correlated the Razorback Beds with the Evergreen Formation of the Precipice Sandstone within the Great Artesian Basin to the west and south west.

Nearly 65 m of Jurassic sediments are exposed near the Mount Morgan Mine. Detailed logging of this section has been interpreted to represent three distinct facies groups; (1) Basal pebbly sandstone; (2) siltstone and (3) cross-bedded coarse sandstone.

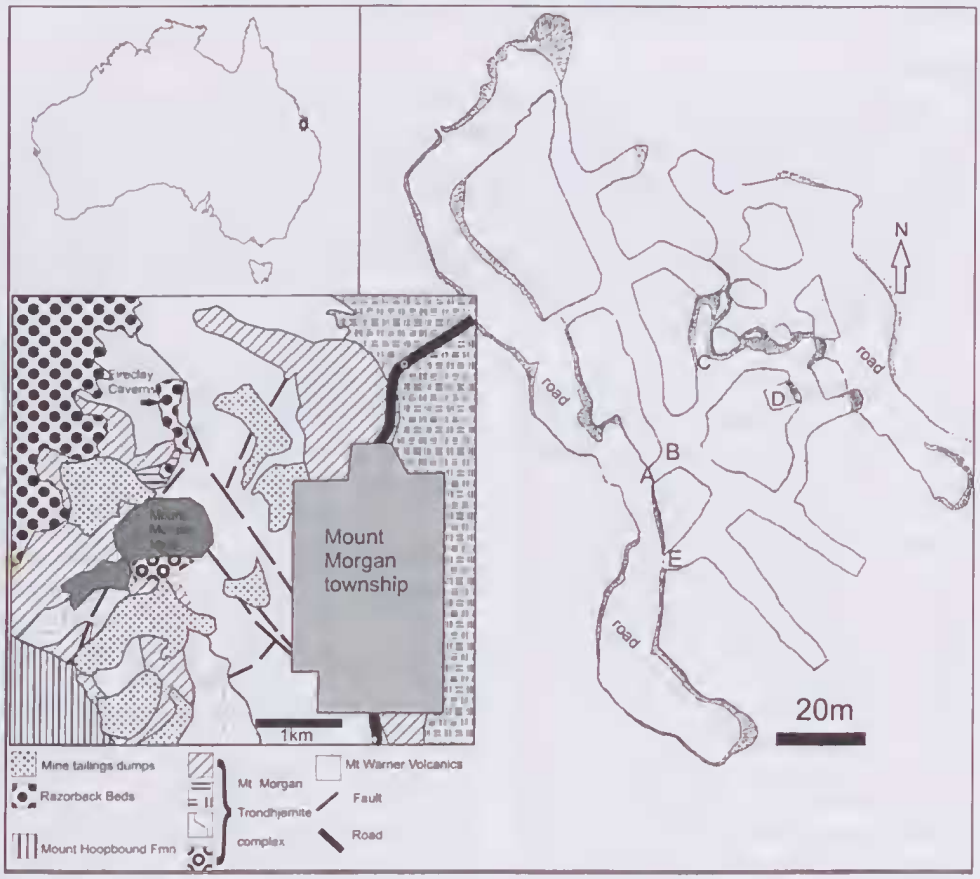

FIG. 1. Locality and general geology of Mt Morgan with map of Fireclay caverns after Staines (1954). Main footprint sites marked A-E.

Basal Pebbly sandstone facies. This facies lies unconformably atop Devonian porphyry and is approximately 20 m thick. Coarse massive quartz and sublithic sandstones, minor polymict conglomerates medium grained quartz sandstone units 0.6-2.2 m thick are intercalated with sporadic mudstone and siltstone units. Minor trough cross bedding and planar laminations are present in the coarser units. Scour bases and lithic breccia lenses are present in the lower parts of coarse units. Generally the facies fines upwards and is directly overlain by the thick siltstone facies described below. The sequence is interpreted as an alluvial fan deposit with sporadic channel and limited floodplain deposition.

Siltstone facies. Two metres of fine-medium siltstone is overlain by monotonous fine-grained laminated siltstone, over 16 m thick which dominates the middle of the sequence. Sedimentary structures include planar and parallel ripple cross laminations, isolated outsize quartz pebbles and subangular clay clasts. Significant pyrite crystals are distributed throughout which are considered secondary given the nature of the proximal orebody. Dinosaur prints are preserved in the uppermost one metre of this facies. The unit is interpreted as a lacustrine system which in uppermost parts shallows to form a regressive lacustrine system onto which footprints were impressed.

Cross bedded sandstone facies. In the study area this forms the uppermost 25 m of exposed section and is dominated by massive and planar and trough cross bedded coarse quartz and sublithic sandstones. Bedding sets are up to 2 m thick and have common basal pebble lags. The facies is interpreted as part of a small braided river system which built out over a restricted lacustrine environment.

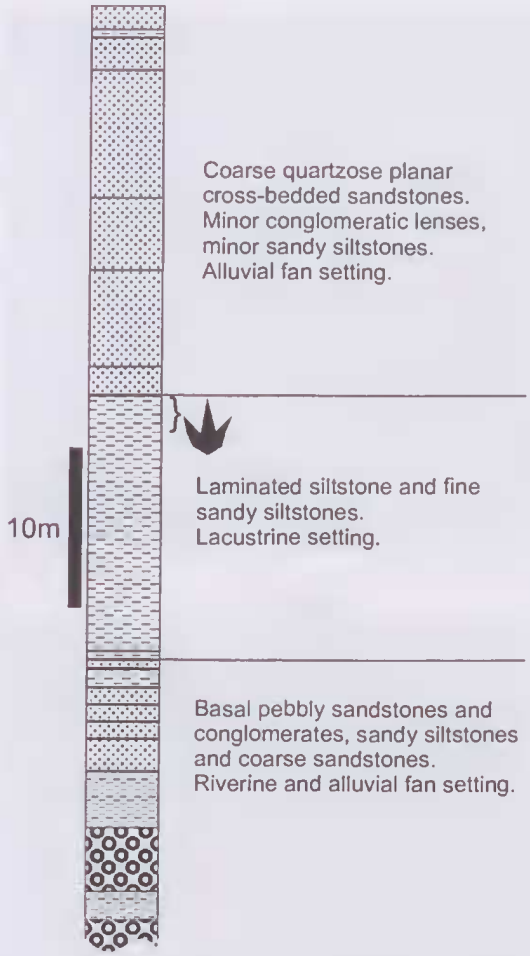

FIG. 2. Stratigraphic column for Razorback Beds in the vicinity of the Fireclay Caverns, Mount Morgan.

PRESERVATION

Footprints are preserved as hyporelief and transmitted hyporelief prints throughout most of the clay caverns mine (Fig. 1). They are preserved in several layers of the uppermost 1 m of siltstone facies within the sequence. Their preservation mostly >10 m above the mine floor was a major impediment to earlier study. In addition the small area in which the prints are less than 5 m above the mine floor could not be cast as the prints were too fragile. This was exacerbated by pyrite growth throughout the siltstone producing large areas of friable and extremely fragile rock. Finally in

2007, using major scaffolding, a small section of footprints was moulded. The mould is lodged with the Queensland Museum (QMF54079).

METHODS

Initial work which formed part of reconnaissance studies (Cook et al., 2002) simply photographed the major footprint-bearing panels. These were then assembled as a photo mosaic for analysis. Two laser devices 10 cm apart were used to provide a scale for further work with photo mosaics. Individual images were either solarised or embossed in Adobe ™Photoshop 7.0. Rectified images were imported into ArcMAP™ 9.0 for further measurement. Because of the large distance between the floor of the caverns and the ceiling, approximately 10 m, all measurements are approximate.

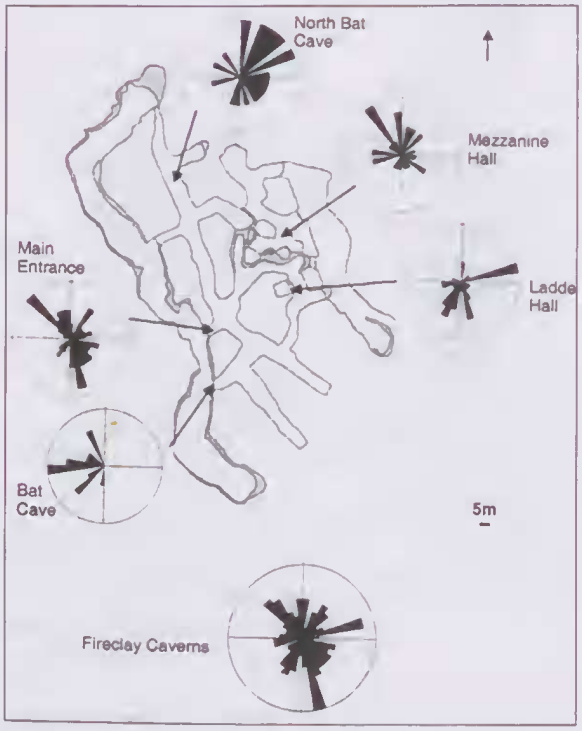

FIG. 3. Rose diagrams showing orientation of footprints within the Fireclay Caverns, with total distribution shown in lowermost rose.

Calculations of hip height follow Alexander (1976) and Thulborn (1990).

DISTRIBUTION

The prints are present in many parts of the mine ceiling. Areas with more concentrated prints sets were given informal names for convenience. Trackways are preserved in 'Bat Cave', 'Main Entrance', 'Mezzanine Hall', 'North Bat Cave' and 'Ladder hall' (Fig. 3).

No preferred overall orientation of prints was observed within the caverns (Fig. 3). Two areas with slight preference for trends of prints directed to the WSW and WNW for 'Bat Cave' and the 'Main Entrance' where there was an EW-NW bipolar orientation.

PRINTS

Only one possible manus print was observed in the caverns despite the observations of Bartholomai (1966) reported in Molnar (1991). Most prints were tridactyl pes prints. Largest prints were that of cf. *Eubrontes* had Foot Length (FL)=40 cm and the smallest, that of *Anomoepus* FL=5 cm. Seven print morphologies were identified, but only three can be confidently assigned to ichnotaxa. Many prints are eroded, with many of their features distorted by erosion. An equally large number of prints are transmitted prints or partial transmitted prints with digit 'breakthrough' from overlying layers. All prints are preserved in hyporelief.

Anomoepus (Fig. 4)

This is the dominant print present within the caverns represented by 69 full prints and 61 partial prints which can be confidently assigned. FL varies from 5 cm to 27 cm with most prints ranging in FL from 10-15 cm. Divaricance

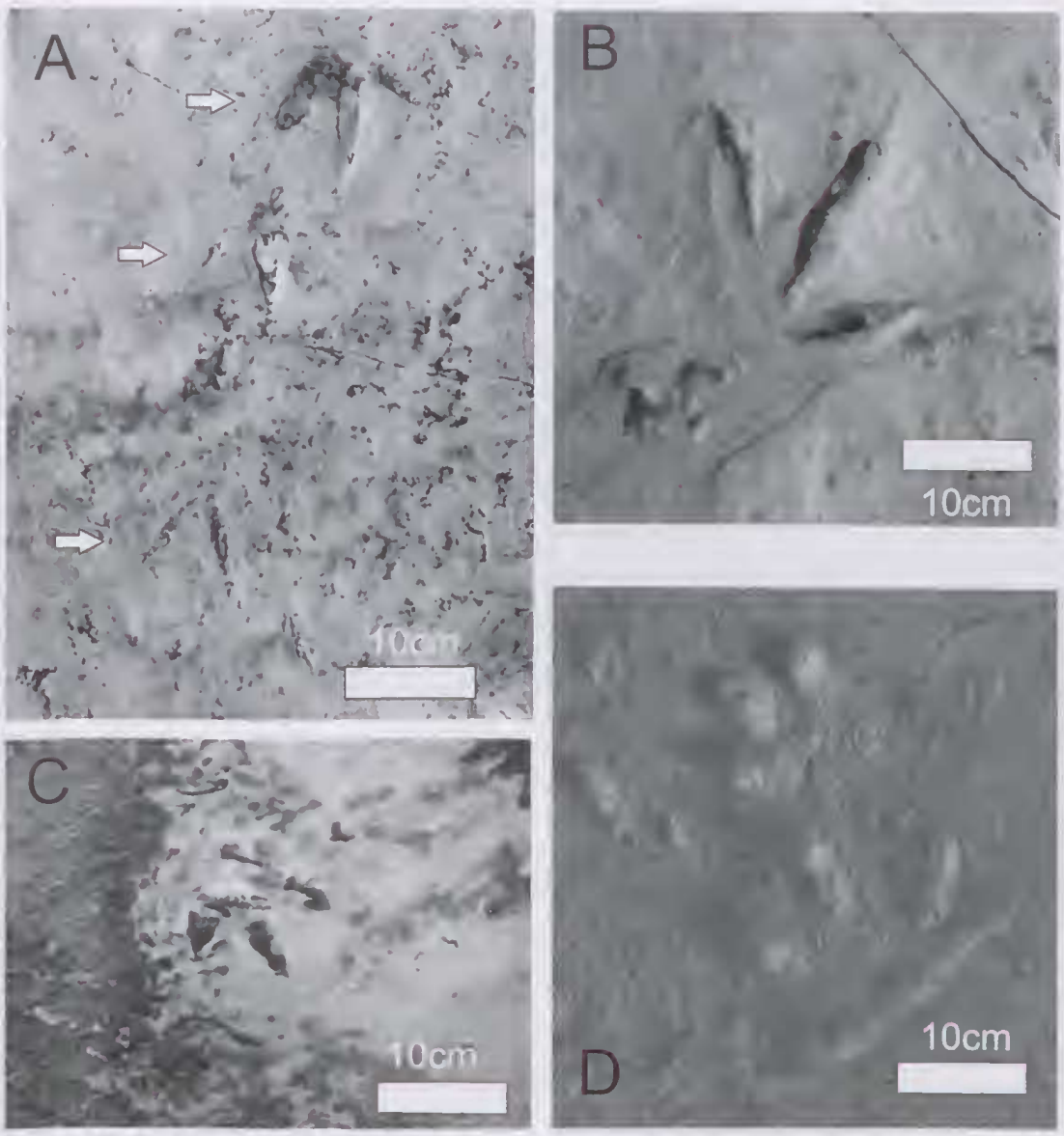

FIG. 4. A-C, *Anomoepus* from the Fireclay Caverns, Mount Morgan; D, Isolated partial pes and possible manus print, *Anomoepus*.

FIG. 5. A, Large transmitted theropod print; B, Stubby-toed ornithopod print. Note tracks are transmitted with breakthroughs on deeper distal digits, especially III.

is between 85-105°. Digits are relatively broad and a semiclaw is present in some specimens. Digits are long and tapered with digit (D) III longer and more tapered than DII or DIV. Slight medial swelling is present on DIII, however there is a pronounced swelling distally on DIV. Distal ends tapered more sharply on DIII, but are subrounded on the other two digits. Interdigital angle is greater on DII-III than DIII-IV.

One print is associated with an additional manus impression (Fig. 4D), consisting of three short stubby digits, approximately 7 cm long, with a divaricance of approximately 85°. These lie just anterior to a distinct partial *Anomoepus* pes print.

Four short trackways are attributable to *Anomoepus*. *Anomoepus* has been recorded in the Precipice Sandstone of Queensland by Thulborn (1994), but the specimens lodged in the Queensland Museum by Thulborn are generally smaller and have slightly narrower digits. *Moyenisauropus* has been used by many authors for prints similar in morphology to *Anomoepus*, but larger than 20 cm FL. A number of authors however assert that the forms are indistinguishable (Lockley & Meyer 2000; Olsen & Rainforth 2003; Olsen & Gatton 1984; Thulborn 1994). For the purposes of this work we regard them as size variants.

cf. *Eubrontes* (Fig. 6)

Fourteen individual prints and one trackway are assigned to this ichnotaxon. FL is between 16-40 cm. The prints assigned to cf. *Eubrontes* differ from *Grallator* in both size and that DIII is reduced in comparison to DII and DIV. In the Mount Morgan prints, the DII-IV divarification is between 50° and 70°. Claw marks are present in three of the 14 prints observed. These represent the largest of the prints at Mount Morgan.

Skartopus (Fig. 8C)

This is represented by a single small tridactyl print with FL of 5 cm, interdigital angles <40°. Digit III slightly longer than others. The single print is distinctive and unlike any other in the Fireclay Caverns. *Skartopus* is known from the medial Cretaceous of western Queensland (Thulborn & Wade 1984).

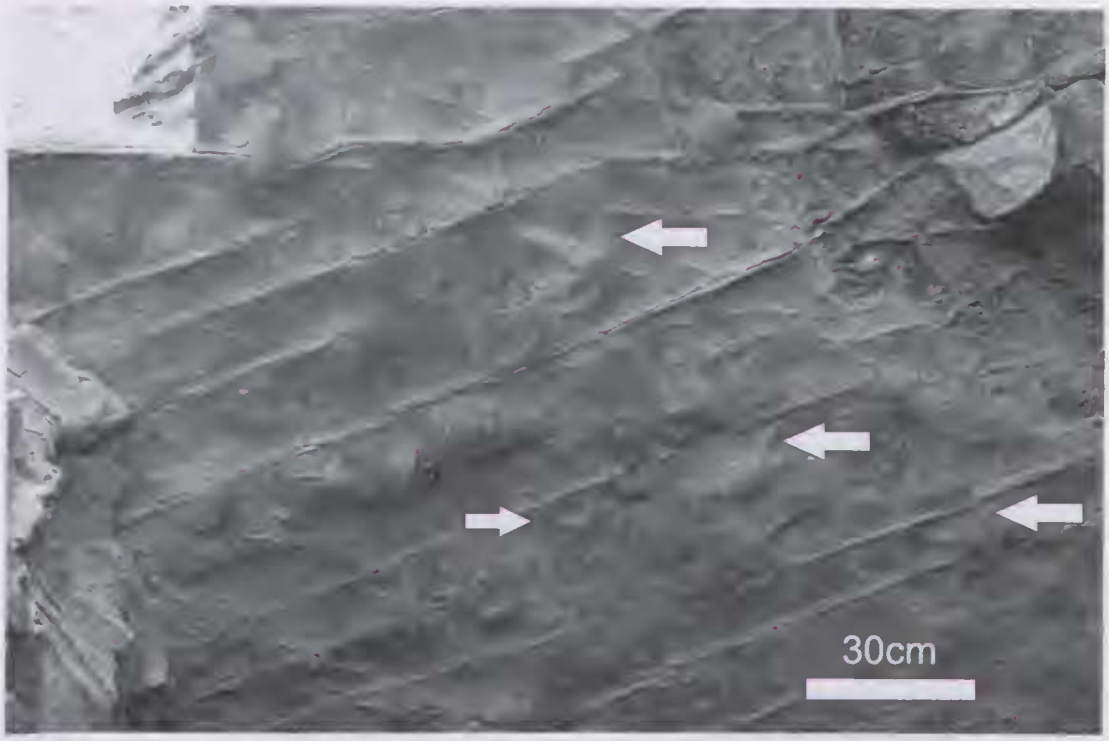

FIG. 6. cf. *Eubrontes* prints forming a short trackway near the entrance to Fireclay Caverns

Grallator (Fig. 5)

Tridactyl print, digit III is longer than DII and DIV, which are nearly equal in length. Divarification is between 85-95°. No hallux impression is present. Most prints are between 4-18 cm in FL but a single, much larger, print 28 cm long is present. This morphotype is represented by 16 complete and 8 partial prints. One short trackway is attributable to *Grallator*. The divarification is high in comparison to types of *Grallator* (Olsen, Smith & McDonald 1998) and other described footprints, but the general foot morphology is consistent. Lack of detail in the phalangial pad marks makes discrimination of individual phalangial swellings difficult.

The earliest record in Australia of grallatoroid tracks is that of Thulborn (1998) who described five prints from the mid-Triassic (Carnian) of Queensland. *Grallator* and its synonyms (Thulborn 1998) are common prints within Early Jurassic assemblages worldwide (Ellenberger 1974; Olsen & Galton 1984; Rainforth 2001).

INDETERMINATE PRINT 1 (Fig 7A-C)

Large tridactyl prints, up to 24 cm FL, with a divaricance of 70-100°. Digits are long and taper to a point. Rear of the print is crescent-shaped. DII-III angle is less than DIII-IV. DIII deep has a medial swelling. Two examples of this print have a probable hallux impression which extends approximately one quarter the distance behind the proximal part of the print. The sharp distal ends of the digit and the size suggest that these prints are attributable to a theropod.

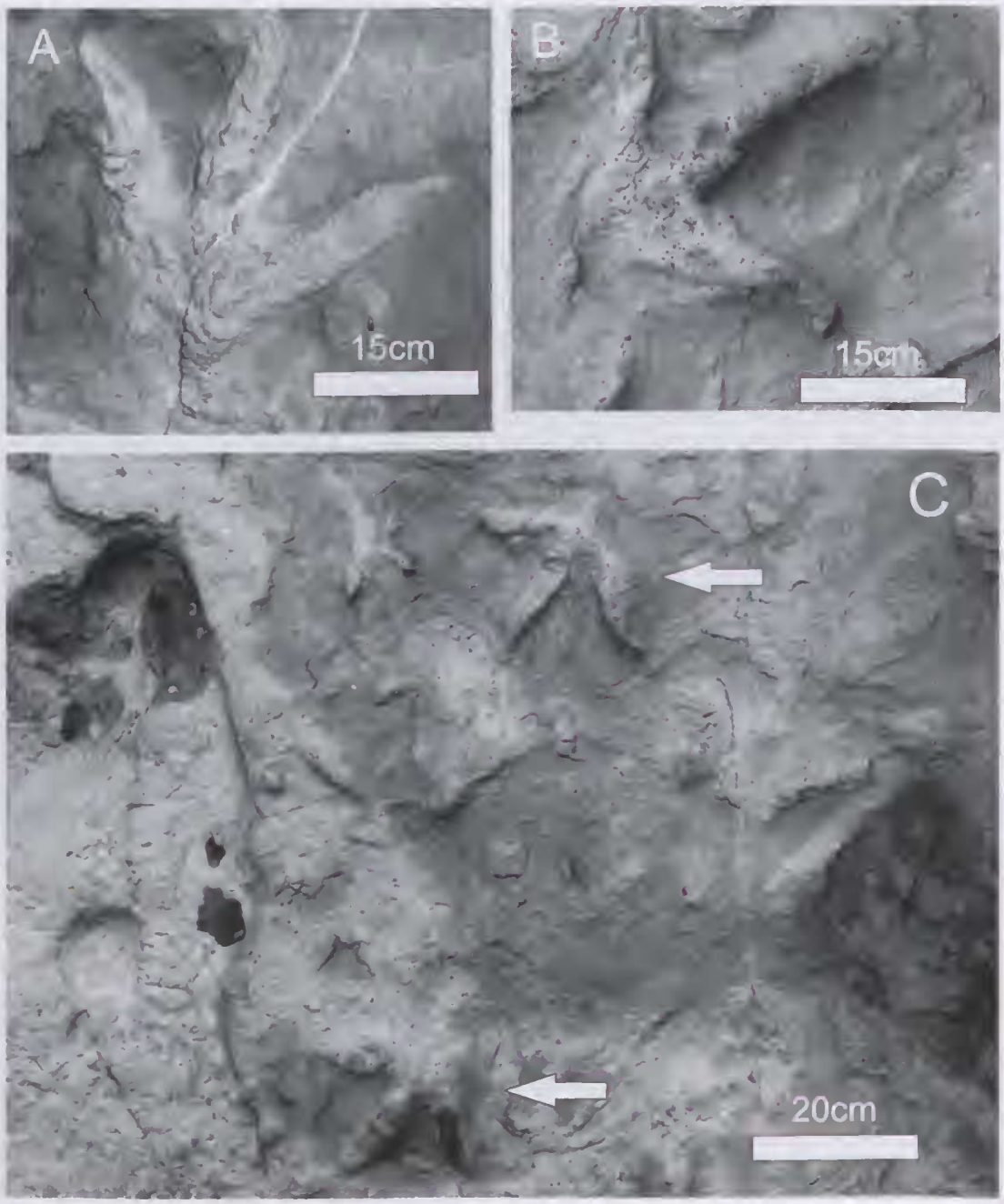

FIG. 7. Large indeterminate, weathered theropod prints.

INDETERMINATE PRINT 2 (FIG. 8A)

FL approximately 8 cm, consisting of three widely divaricant digits with an overall divaricance of 95°. Digits are short and blunt with rounded distal ends. DIII is slightly longer than DIV and has a slight swelling approaching the distal margin. DIV deep. DII shallower with less pronounced swelling at the distal end.

This print differs from Indeterminate print 3 by its wider divaricance and the connectedness of the digits. The blunt nature of the prints suggest an ornithopod origin.

INDETERMINATE PRINT 3 (Fig. 8B)

Foot length is approximately 12 cm. Print consists of three blunt digits with a divaricance of 50°. DIII longer and deeper than DII and DIV, with DIV longer than DII. Slight swelling at the proximal end of DIII. The three digits are almost unconnected on the print. The blunt toed nature of this print suggests an ornithopod origin

SIZES OF PRINTMAKERS

Thulborn (1990) suggested that the approximate relationship of FL to hip height and his formulae and conversion factors are followed here. *Anomoepus* prints suggest most animals with a hip height of 25-131 cm. One example suggested an animal with a hip height of 161 cm, but this single print is aberrant. Prints ascribed to cf. *Eubrontes* suggest animals in the range 70-180 cm at the hip and those assigned to *Grallator* indicate hip heights of between 20-120 cm.

ASSEMBLAGE

The variety of the prints within the assemblage is skewed by our decision to lump ichnotaxa. Nevertheless what is striking about this fauna is the high percentage of anomoepid prints in relation to theropod prints (Fig. 9). Prints attributable to ornithopods constitute just over two-thirds of the assemblage. This is in contrast to other Triassic-Jurassic assemblages worldwide which show greater percentages of

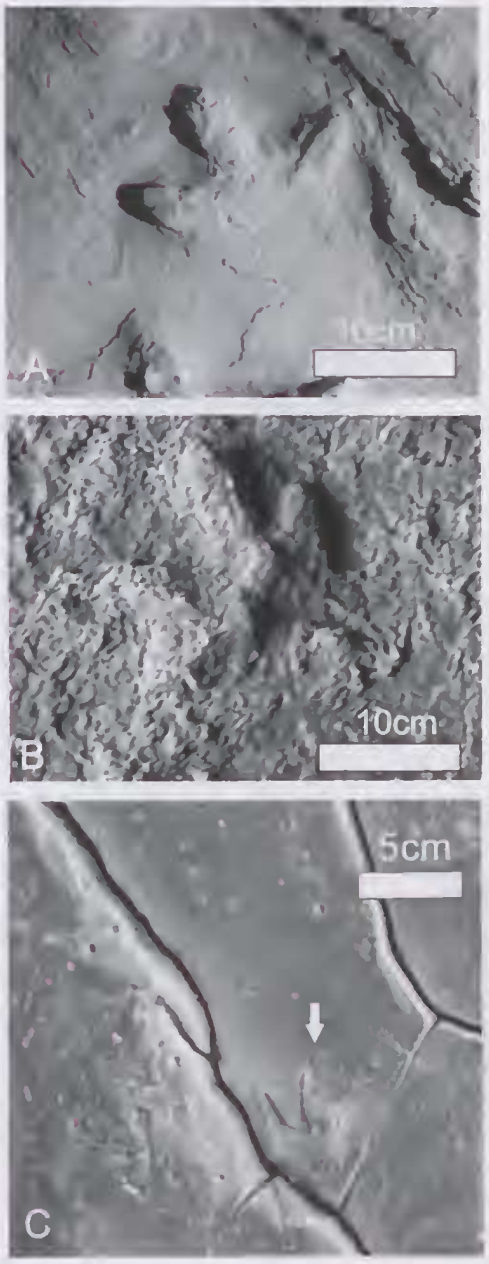

FIG. 8. A,B. small, blunt-toed probable ornithipod prints. A, digits show wide divaricance; B, Digit impressions only with moderate divaricance; C, Isolated *Skartopus* print.

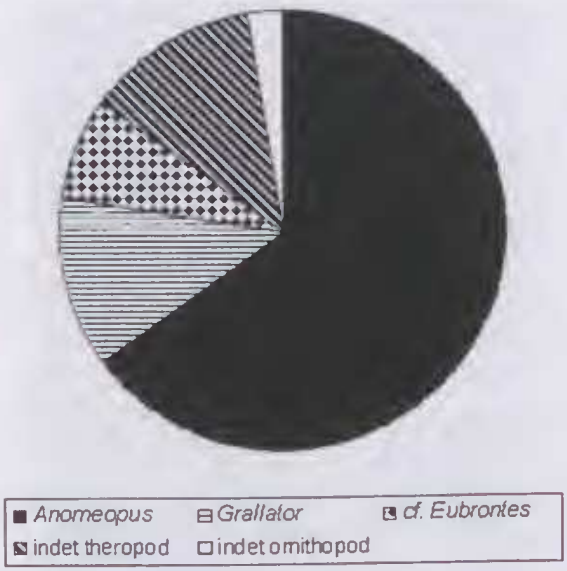

FIG. 9. Pie chart of proportions of prints found within the Fireclay Caverns. n=192. Single *Skartopus* print included in indeterminate theropod prints.

grallatoroid and other theropod prints (Lockley & Hunt, 1995; Lockley & Meyer, 2000, Gierlinski & Sawicki, 1998; Gierlinski & Niedzwiedzki, 2002; Niedzwiedzki & Pienkowski, 2004). A possibility is that the ecological setting for the site, essentially at lakes edge could account for the greater numbers of ornithopods, utilising the lake as a regular watering hole.

TRACKWAYS

Six trackways (Fig. 10) are present in the clay caverns, the longest of which is represented by 6 successive prints. Three are attributed to *Anomeopus* and of the remaining one to ?*Eubrontes* and two to *Grallator*. Pace lengths and other data are summarised in Table 1. Stride length to hip height ratios (Alexander 1976, Thulborn 1990) are all less than 1.3 indicating cursorial gaits for all the short trackways present. Data is too incomplete to make any other meaningful comment on speeds, however it is clear all the trackways represent walking tracks.

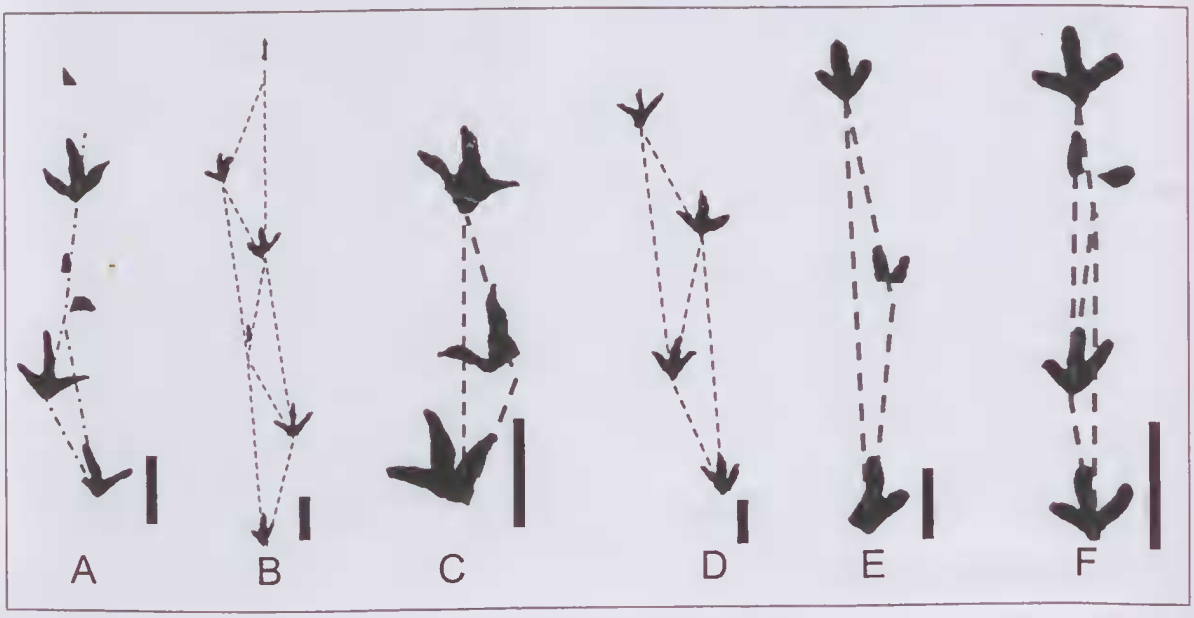

FIG. 10. Diagrams of the six short trackways within the Fireclay Caverns.

TABLE 1. Morphometric data for trackways within the Mt Morgan Fireclay Caverns.

Track and Print field number	Full/ partial print	Length (cm)	Width (cm)	Right/ left	Pace Length	Stride length	Pace angulation	Direction/ azimuth	taxon
LHT1									*Grallator*
LHFP26	F	8	7.1	L				198	
LHFP27	P	4.4+	4.5+	R	28.3		163	194	
LHFP28	P	9.9	5.7+	L	28.5	56.4		211	
LHT2									*Anomeopus*
LHFP33	F	9.5	10.4	L	19	43.4		171	
LHFP34	F	8.8	9.3	R	24.6		168	170	
LHFP35	P	5.6+	8.2	L	12.6	37.7	173	165	
LHFP36	F	10.4	11.4	R				165	
MET1									*Anomeopus*
MEFFP15	F	19.2	23	R	20.9	52		322	
MEFPP14	P	15.5+	14.3+	L	31.1			321	
MEFPP17	f	16.9	20.2	R				337	
MET2									*Grallator*
MEBFB30	F	17.5	15.7	R	42	102		191	
MEBFB19	F	18.5	18.4	L	60	98.5	145	182	
MEBFB18	F	18.7	21.7	R	37		138	209	
MEBFB11	F	16.4	19.6	L				213	
BCT1									*?Eubrontes*
BCFP5	F	21.9	22.6	L	26.9	63		262	
BCFP4	P	6.2+	7.3+	R	35.7	61	173	263	
BCFP3	F	20.6	20.7	L	24.8		180	276	
BCFP2	P	5.6+	4+	R				285	
EHT1									*Anomeopus*
EHFP4	F	16	11	L	56	101		227	
EHFP5	F	17	19	R	46	90.7	135	229	
EHFP6	P	9.0+	2.2+	L	47	87	143	227	
EHFP7	F	16	17	R	40	99	142	230	
EHFP8	F	14	14	L	59		127	226	
EHFP9	P	11.4+	1.9	R				228	

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